

Practical 10GHz Gunn oscillators

by DAIN EVANS, G3RPE*

GUNN oscillators are an attractive means of generating useful amounts of power at 10GHz. Compared with klystrons, a widely used alternative rf source, they have the advantages of requiring a relatively simple power supply (typically up to 10V at 150mA for low power devices), they drift little on switching on, and can be tuned perhaps up to 500MHz by a single knob control. Like klystrons they are easily modulated to produce wide-band fm of highly acceptable quality, and can be readily fitted with an automatic frequency control. Most important, Gunn diodes, the low-power types only, are available on the surplus market at a moderate price. At present high power versions which generate typically 500mW do not yet seem to have percolated through to the surplus market.

The output power of the low-power types, of which the Mullard CXY11 series are examples, is in the range 5 to 15mW. This makes them ideal as local oscillators for receivers where the reserve power available, 10 to 15dB, makes possible a simple yet efficient method of oscillator injection. This level of power is also adequate for a transmitter: the potential range over line-of-sight paths to be expected varies from about 50 miles when using dishes 1ft in diameter to 1,000 miles when using dishes 3ft in diameter [1]. Practical experience supports these estimates: a UK record of 154km was first established using low-power Gunn oscillators in both transmitters—and there was 20dB in hand.

Many oscillators which have been built prove very difficult to get to work properly. Most problems appear when an

attempt is made to tune them over a usefully wide range, when erratic tuning is observed. At its simplest, this may be due to poor mechanical design or bad engineering, and is easily rectified. A common fault is frequency jumping: as the tuning mechanism is operated, the frequency changes progressively and then jumps by perhaps a few megahertz or even hundreds, to continue tuning in a different mode. In other cases, the oscillator may stop oscillating, remain tuned to the same frequency—or even tune backwards. Other faults observed are the undue sensitivity of frequency to the match of the load or to the applied working voltage (which can raise problems in modulating), and the generation of spurious outputs.

These latter faults are rather difficult to understand as it is common experience that a particular Gunn diode behaves differently in a particular cavity: a "bad" diode in one cavity can give excellent results in another, even if this is of identical design. The "rule" of semiconductors, that if the circuit does not work then change the semiconductor first, seems to have even greater significance with these negative resistance devices. For this reason it is not possible to present a sure-fire design which will guarantee success with all diodes. What can be done, however, is to present various designs which individuals have found to work well, to point out the significant features of each type, and to make some general points on constructing these oscillators.

It must be emphasized that much of the so-called design is quite empirical and frequently depends on the individual's

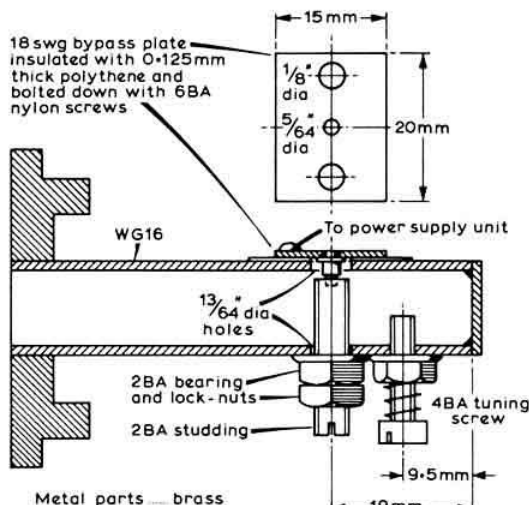


Fig 1. A simple Gunn oscillator by G2RY

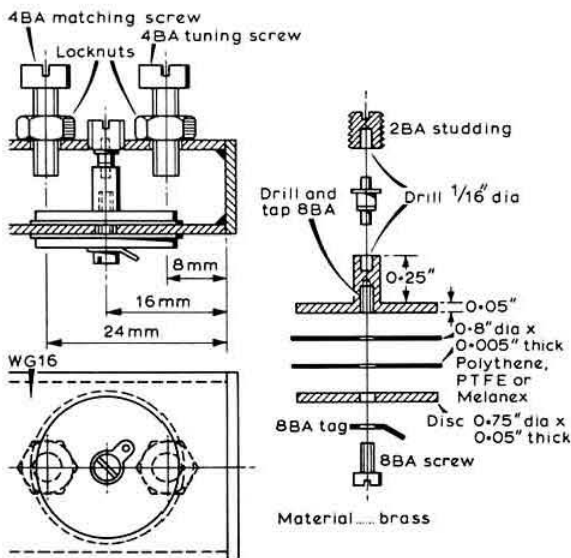


Fig 2. The GM8BKE design for a simple Gunn oscillator

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Practical designs

Just how simple an oscillator can be is shown by Fig 1, due to G2RY. The design is based on an even simpler one contained in a Mullard pamphlet [2] which unfortunately is no longer in print. As mentioned above, many of the problems with Gunn oscillators result from trying to make them tunable. G2RY avoids this by using one oscillator as a transmitter preset in frequency, and a second as the fixed-frequency first local oscillator of a double superhet, the second i.f. at vhf being the one tuned.

The method of construction is evident from the figure. Note that in this design, and in the others described later, the Gunn diode is positioned centrally within the guide.

A similar design, due to GM8BKE, is shown in Fig 2. So far, six have been built and all have performed reliably. As with the G2RY device, the tuning screw is used to set the frequency of oscillation and is then fixed by the lock nut. Tuning the receiver again is done via a tunable i.f., in this case by a standard 110 to 170MHz fm receiver. With the dimensions given, the normal tuning range is 10.0 to 10.2GHz, although the maximum tuning range at reduced power output is 9.9 to 10.3GHz. The pillar and disc on which the diode is mounted may be made from separate pieces to be bolted together with the 8BA screw when the whole choke assembly is put together.

From what has been said earlier, rather more complicated designs are to be expected if the oscillator is to be tuned, and the one given in Fig 3, due to G8DEK, is an example of this. The rf choke is designed to have a low Q to reduce the tendency of the Gunn diode to resonate with it, and is larger in diameter than in some other designs to place extra capacitance across the diode. Another feature is the use of two matching screws which are critically spaced from the diode. A basically similar design by the author is shown in Fig 4. It was published some time ago [3] and about half of the oscillators made have worked well. The use of a wedge to ease the problem of matching the diode to the guide does not appear

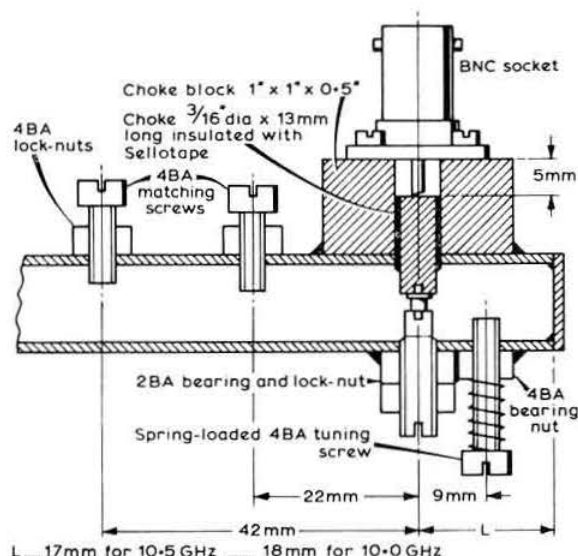


Fig 3. G8DEK design. Note the use of critically spaced matching screws

sense of engineering and components available. For example, the diameter of the choke feed in a number of designs is 0.375in. This started as being one person's view of what appeared to be about right, and grew by default into a "standard". There is no reason to believe that one 0.3 or 0.25in in diameter should not be used if this is more convenient. It is hoped, therefore, that people will be tempted to experiment with modified designs to suit their ideas and facilities, and that they will pass on the results of their experience.

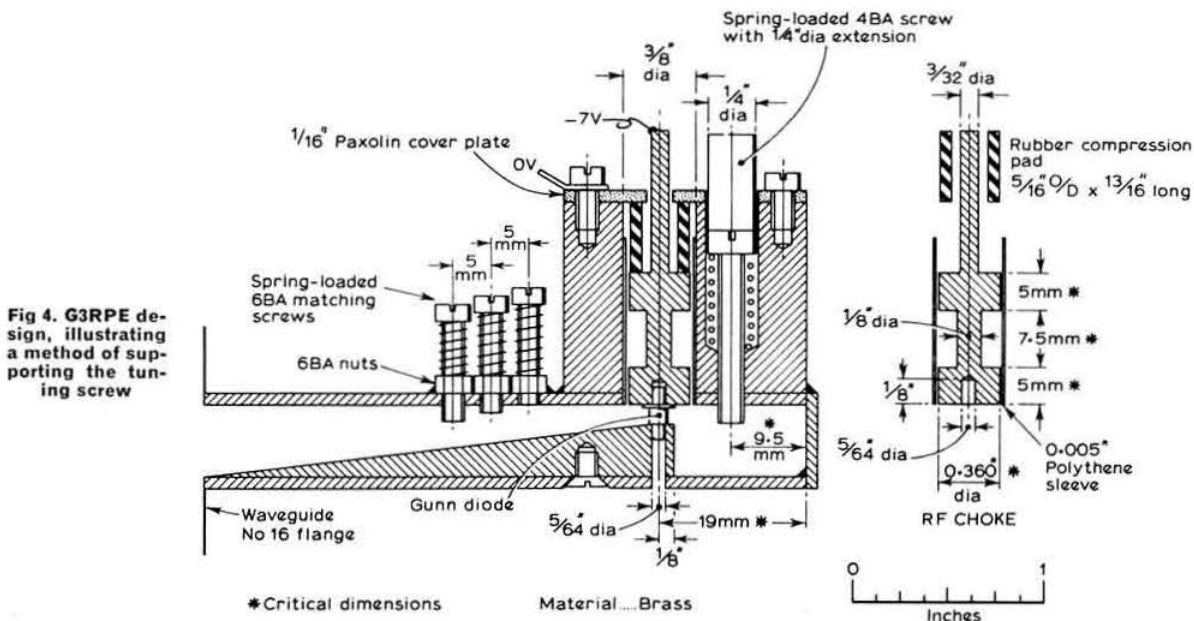


Fig 4. G3RPE design, illustrating a method of supporting the tuning screw

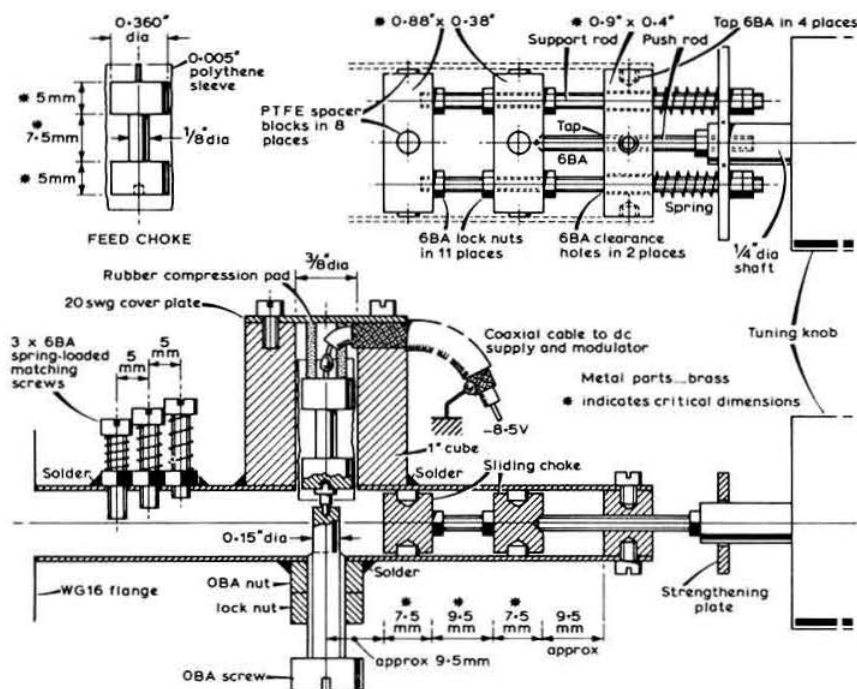


Fig 5a. G3ZGO design, using a sliding short for tuning

in the light of experience to justify the extra effort involved in its manufacture and fitting. However, the design is worth showing again to illustrate one method of engineering the tuning screw assembly which has proved reliable in use over the years. The $\frac{1}{8}$ in diameter shaft is driven by a 6:1 reduction drive via a flexible coupler.

These last two designs also indicate a difference in philosophy with regard to terminating the dc feed. The first uses a conventional coaxial socket which gives improved screening and is neater and safer. The second has the end exposed so that it can be more easily checked that it is "cold" to rf, or if not, something can more easily be done about it.

In these three designs, the maximum frequency of oscillation is set mainly by the length of the cavity formed between the diode and the closed end of the waveguide. Inserting the tuning screw lowers the frequency. The cavity is electrically $\lambda/2$ long. Its physical length approximates to $\lambda_g/2$, where λ_g is the wavelength in the waveguide in use. For waveguide 16 usually employed (inside dimensions 0.4 in $\times$ 0.9 in), λ_g is equal to 39.70, 39.02 and 38.37 mm respectively at 10.0, 10.1 and 10.2 GHz. These figures also give a guide to the degree of accuracy required in construction: a difference in length of 1 mm corresponds to approximately 300 MHz. To achieve the required level of accuracy in manufacturing, the author has found it easier to first define the position of the diode by drilling a pilot hole through both walls of the guide, and then carefully trimming to the necessary length, rather than trying to drill the hole a precise distance from the end. A convenient method of measuring the length is to reinsert the drill in the holes and measure the length between the end of the guide and the outer face of the drill, and then, of course, subtract half the diameter of the drill. A second approach which can also be recommended is to close the guide with a fairly tight

fitting brass block, and firmly clamp it in place with several screws after its position has been adjusted.

The G3ZGO design given in Fig 5a is similar to those above, the essential difference being that the tuning is done by varying the effective length of the cavity directly rather than by a tuning screw. Because the tuning rate is very high (hundreds of megahertz per mm), precision in the manufacture of the drive mechanism must be of a high level if smooth tuning is to result. That this can be achieved by nominally unskilled amateurs with limited facilities (no offence intended) is one of the more surprising aspects of this type of activity; that it can be achieved using unsophisticated components is a feature of this particular design.

A more complex drive is shown in Fig 5b in which the mechanics for aligning the sliding choke accurately are separated from those for moving it. Any free movement in the rear bearing has a reduced effect because of the long lever used. The drive mechanism shown uses a micrometer head which produces a backlash-free drive and which also provides an accurate calibrating facility. Alternatively, an ordinary screw can be used. In both cases a reduction drive is necessary.

It is also important that the sliding choke is a good fit in the guide so that it cannot wobble, and that it either makes excellent electrical contact with the guide or that it is reliably insulated: partial contact results in erratic tuning. In the designs shown in Figs 5a and 5b, the choke is "floated" on pips of dielectric protruding about 0.010 in. The method used by G3ZGO to make an accurate insert is to drill a $\frac{1}{8}$ in diameter hole about $\frac{1}{8}$ in deep in the choke, and to press in a suitable piece of dielectric: the body of a standard pte feed-through insulator is ideal. The pte is cut off flush with the surface and the insert is removed with a needle. The bottom

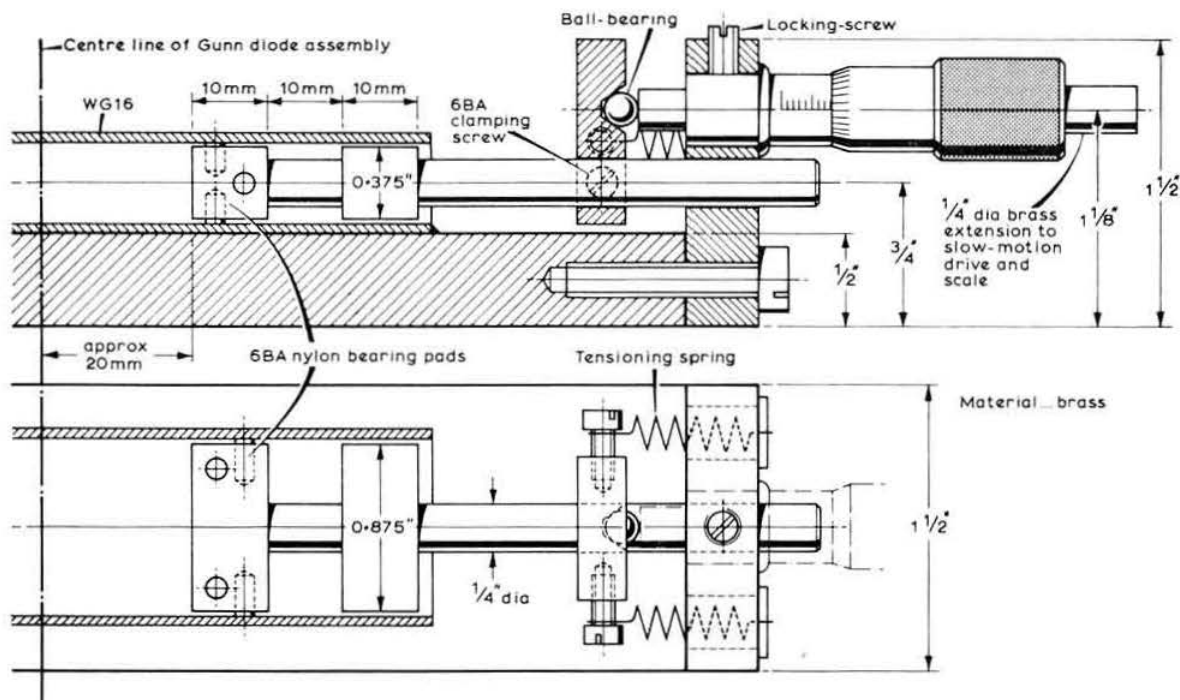


Fig 5b. Alternative drive mechanism

of the hole is then packed with material of thickness equal to half the difference between the size of the choke and the dimension to be fitted, and the insert is finally replaced.

The method used by the author is to drill a 6BA tapping hole in the choke and tap a thread just sufficient to take a 6BA screw. A nylon screw is screwed in, tightened and cut roughly to length. Using silicon carbide paper, the insert is progressively trimmed until the total thickness as measured with a micrometer is, for example, 0.3875in ($0.375 + 0.0125$). This is repeated with the opposite insert and trimmed until the total thickness is 0.400in. When all the inserts are fitted, they are gently rubbed down so the choke is a smooth sliding fit in the piece of waveguide to be used. By means such as these it is quite easy to work within fractions of a thousandth of an inch, and thus effectively eliminate play.

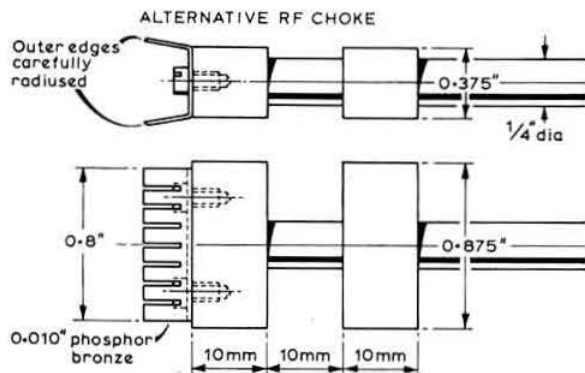


Fig 5c. Alternative choke design

In the alternative method of making chokes shown in Fig 5c, good electrical contact is ensured by using fingering. The ends of the fingers should be carefully radiused with fine

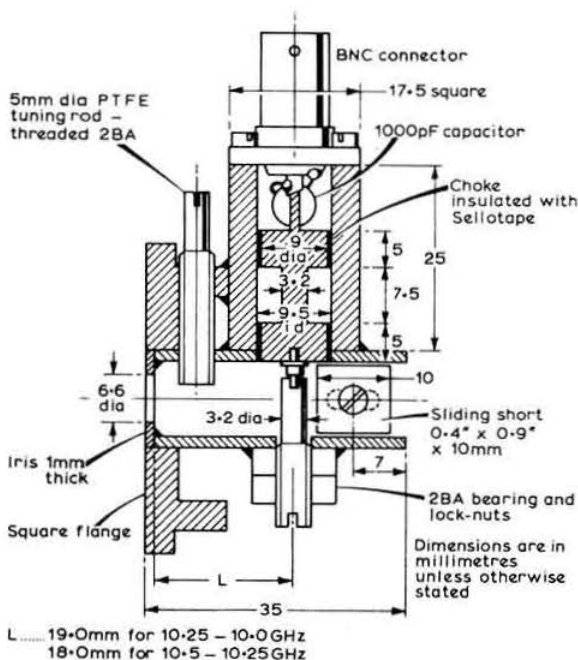


Fig 6. G3WJG design with dielectric tuning screw

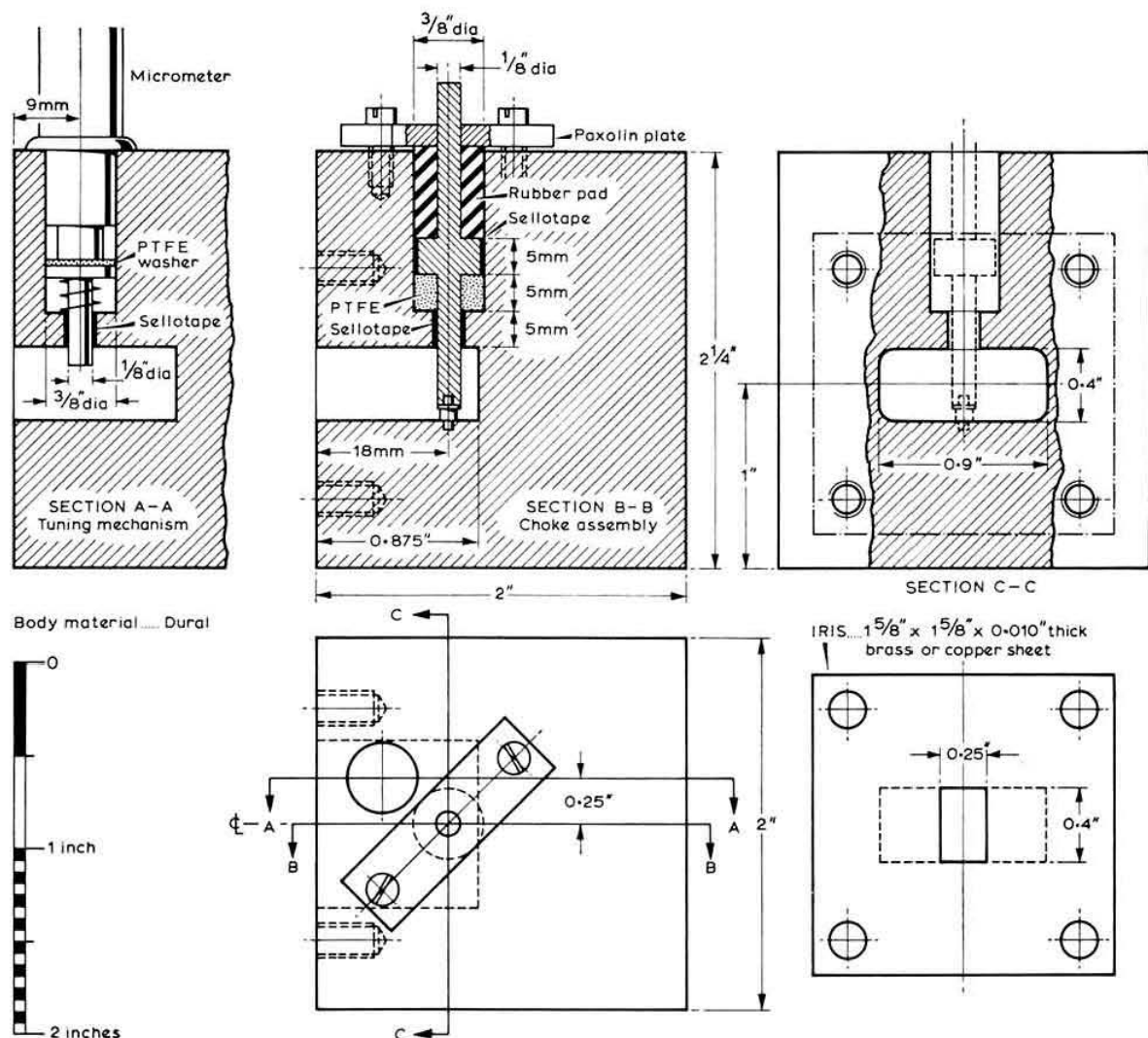


Fig 7. G8APP design. Note the use of an external iris plate and choked tuning screw

silicon carbide paper so that adequate contact pressure can be used without scoring the walls of the waveguide.

The designs given in Figs 6 and 7, due respectively to G3WJG and G8APP, show the different realizations of the same basic design: a sketch is given in "Gunn Diode Application Notes" by Microwave Associates. In these oscillators the upper frequency is set mainly by the length between the diode and the iris: the length between the diode and the rf short is uncritical and is optimized for maximum power output. A significant feature of the G3WJG design is the use of a dielectric tuning screw which tunes about 250MHz for eight turns. With this oscillator care must be taken to prevent a short circuit between the rf choke and the sliding short.

The design by G8APP has a number of notable features: the use of a massive dural block to provide a large thermal mass; the tuning screw mechanism itself and the fact that it

is offset to reduce the rate of tuning; and the use of a separate iris which is clamped between the body of the oscillator and the flange terminating the external circuit. The latter feature has two advantages. Firstly, the size of the hole is quite critical: if too large, the frequency of oscillation is unduly affected by the external circuitry, and if too small, the power output is limited: ease of changing the iris is a useful facility. The second advantage is that it allows the length of the cavity to be adjusted, which is valuable as there is always some uncertainty about the precise frequency a particular cavity will tune.

The design given in Fig 8 is an attempt by the author to combine the best features of the G8APP and G3WJG designs: it uses both the general method of construction and the dielectric tuning of the latter design, and the choke and externally fitted iris of the G8APP design. Four oscillators

have so far been made, and all have been reliable even when using diodes which have behaved erratically in other cavities. The only setting up that has been used was to increase the voltage applied until oscillation was reliable both in starting and running, and to adjust the position of the rf short to maximize the output.

The dielectric tuning mechanism has been found to work most smoothly over a tuning range of at least 300MHz, the tuning rate being about 30MHz per turn. A nylon screw also works well, producing a faster tuning rate, but is probably more prone to loss. The positions of the band-set and the tuning screw may of course be interchanged.

The only critical dimension in its design is the length of the cavity from the centre line of the diode to the face of the flange: the frequency of oscillation varies by about 300MHz/mm. However, it is quite practical to raise the maximum frequency of oscillation of a cavity significantly by machining off the appropriate thickness of metal from the face of the flange, even without dismantling the cavity! It would probably be satisfactory to lower this frequency by fitting a spacer between the flange and the iris plate.

The method of constructing the body of the oscillator can be as follows:

- Drill a hole (No 52 drill or similar) through both broad faces of the waveguide about 20mm from the flange end.
- Drill the choke plug initially with this drill.
- Drill a 5/16in diameter hole in the choke block off centre so that the dimension x , as given in Fig 8, plus the thickness of the flange to be used is equal to the length of cavity required.
- To jig for soldering, fit the drill in the holes in the waveguide, slip on the choke plug, fit the choke block and slide on the flange until it meets the choke block. After soldering, open out the hole in the plug to 9/64in diameter.

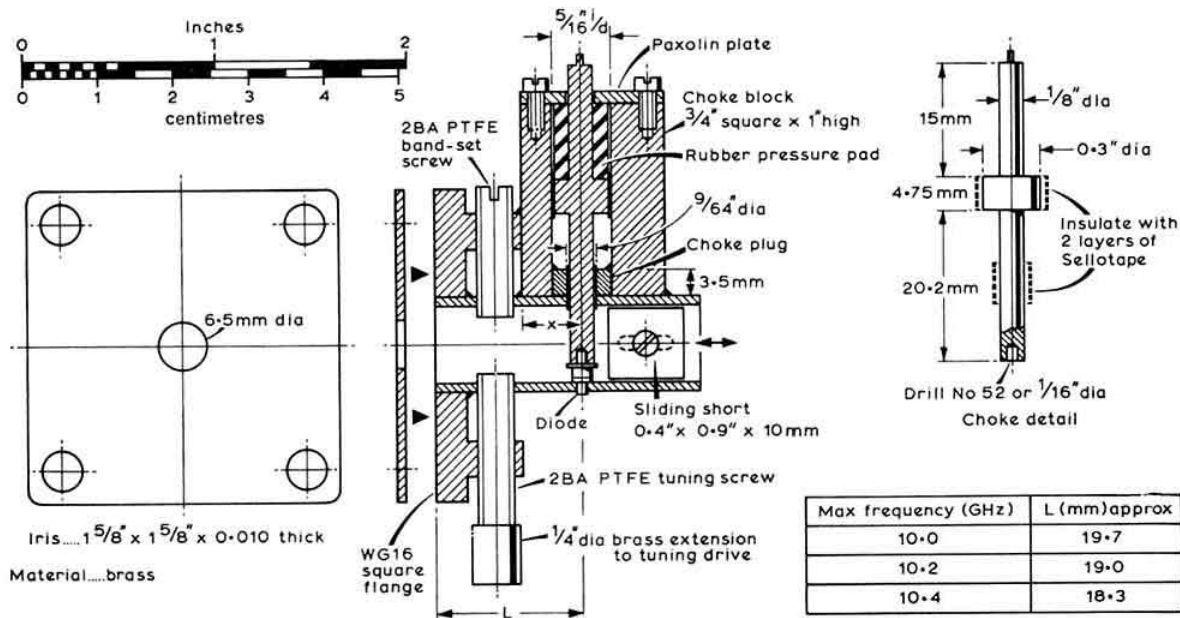


Fig 8. Modified G3WJG/G8APP design

The tuning of Gunn oscillators

Although Gunn oscillators can be tuned by varactors, amateurs do not seem to have explored this technique, presumably because suitable varactors are not yet available at amateur prices: as has been illustrated above, mechanical tuning methods have been preferred. Some important points with regard to sliding shorts have been made earlier: the following makes points about tuning screws and of improving their reliability of operation.

The tuning rate of a metal screw depends on the degree of penetration, and ranges from a few megahertz per turn as it just enters the guide up to tens of megahertz per turn when several millimetres are inserted. It is desirable, therefore, that the tuning screw should be operated with the minimum penetration for the most reliable operation. This implies that the highest frequency required should be set by other means: for example by adjustment of the physical length of the cavity, or by a second tuning screw which is firmly locked in position after setting; the length of the screw inserted being clearly well defined. With a metal tuning screw there should be reliable electrical contact between the screw and the thread in which it runs. This is aided by limiting the number of threads in contact to three or four, tapping the thread only sufficiently to clear the screw, and the use of an adequate spring to eliminate backlash.

The tuning screw itself should be well supported so that it cannot wobble (see Fig 4), and care must be taken not to unduly load it by the external drive mechanism. Note that if one screw is a little loose in its thread, there is usually sufficient variation in a selection of screws to enable a better fitting one to be found. Gold plating of the contact surfaces would probably be an advantage, although this has not been tried by amateurs as far as is known.

An attractive method of avoiding contact problems is to use a dielectric tuning screw, which is a feature of the designs shown in Figs 6 and 8. It needs to be of a larger diameter than

the corresponding metal screw. Ptfе appears to be an ideal material, although a sharp die is necessary to cut a clean thread. As noted above, the tuning rate for a 2BA screw is about 30MHz per turn: if this rate is inconveniently low it may be practical to use a screw of larger diameter or possibly one of a material such as nylon if the extra loss can be tolerated.

A second method of avoiding contact problems is shown in Fig 7, in which the "cold" end of the tuning screw is defined electrically rather than mechanically by a $\lambda/4$ choke. A variation on this technique would be to use the micrometer shaft itself as the tuning element in a way similar to that described for an absorption wavemeter [4]. To reduce the high tuning rate to be expected, the micrometer shaft should be as small in diameter as is available, and should be offset from the centre of the guide.

Finally, as much care should be lavished on the design and construction of the tuning drive and scale as that at lower frequencies. After all, the demands on precision, at least one part in a thousand, are of the same order.

Precautions with Gunn diodes

Gunn diodes are relatively indestructible devices: being quite small (see Fig 9 for typical dimensions), probably as many have been lost by dropping as by overloading. However, there are a number of precautions which should be observed in their use:

- With low power diodes there is no major heat-sinking problem. Diodes may therefore be used either end up to suit the polarity of the rest of the equipment, although their thermal stability will be improved if the heat sink end is connected to the body of the cavity rather than to the choke system. To improve heat-sinking, the heat-sink end of the diode should be a tight fit in its mount and the contact area should be maximized by removing burrs. A trace of heat conducting grease may be applied to this connection. Although the encapsulation is quite strong in pure compression, shear forces should be kept very small. The flanged end of the diode should therefore be a loose mechanical fit in its mount to allow for any misalignment.
- The diode must never be operated with reversed polarity. They require 7 to 10V at 140mA under normal operating conditions. At lower applied voltages a much higher current is drawn, so the full working voltage should be applied directly.
- Being negative resistance devices, the diodes will tend to oscillate with any stray inductances. They are particularly prone to produce spurs at vhf and to prevent this Microwave Associates suggest a suppressor consisting of a 10 to 100 Ω resistor in series with a 0.01 μ F capacitor fitted at the cold end of the rf choke feeding the dc. The author has heard of two failures which were attributed to parasitic oscillations at audio frequency due to the diode being operated via the secondary of a modulation transformer, the primary being undamped. It is also worth fitting a zener diode at the cold end of the rf choke to eliminate voltage spikes. It should be rated at about 0.5V above the maximum working voltage, including modulation and afc voltages.

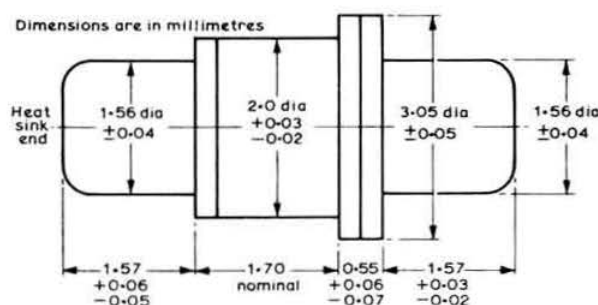


Fig 9. The outline dimensions of a typical low power Gunn diode encapsulation

- With more powerful diodes there is the risk that the power density at the end of the waveguide may exceed the maximum safe level of 10mW/cm². The density falls to a much lower level even at a few inches away from the end of the guide, but nevertheless care should be taken at all times.

Setting up and operating

Wide-band operation in the UK is firmly established in the range 10.0 to 10.1GHz, with preferred operating frequencies at 10.035 and 10.065MHz, and the oscillators should be set up with these frequencies in mind. A psu, wavemeter and some means of indicating relative power levels are the minimum necessary equipment. The latter could conveniently be a mixer/detector, but if fed directly it should be via an attenuator of at least 5 to 10dB to prevent damage to the mixer diode and to provide a reasonably well matched load for the oscillator. Alternatively, a convenient test unit can be the transmitter or receiver with which the oscillator is to be used, an example of one configuration of which is given in an earlier article [5]. This article also gives references to the design of components which may be used.

The psu should be stabilized, but not necessarily to the highest standards as the frequency sensitivity to voltage is usually less than 20MHz/V, depending on the Q of the cavity and the applied voltage. It should be adjustable over the range at least 7 to 10V, and to be able to supply up to about 200mA. Before use it should be checked that it is free from parasitic oscillations, as many are vulnerable in this respect. A suitable psu/modulator and its associated afc unit have been described earlier [6, 7].

Setting up is largely a matter of systematic adjustment of the applied voltage, and of matching screws, iris dimensions and preset tuning controls as fitted, until smooth tuning over the frequency range required is achieved with an acceptable power output. This process may take a matter of minutes or many hours. Usually it will be found that a basically stable oscillator will respond smoothly to any adjustment. On the other hand, an oscillator which is over-sensitive to the applied voltage, for example, will also probably be strongly dependent on the position of matching screws. Generally it is unwise to try to extract the maximum power possible, since this may involve a heavy price in terms of stability, as the difference in performance obtained when operating at, say, half power is only rarely detectable in use.

Initially about 7V should be applied and the voltage increased only sufficiently to start oscillation to achieve the objectives required. A working voltage of 9V is not unusual. In the absence of more elaborate test equipment, a good indicator of performance is the output power: if the oscillator is working well, this should vary smoothly on tuning with perhaps less than 20 per cent change over a 500MHz range. If the power output changes abruptly, this may indicate that the oscillator has changed its mode of oscillation, which can be checked by taking systematic frequency measurements. It may also indicate that the oscillator is generating spurious frequencies. If the oscillator is used as the local oscillator of a receiver, this may be heard as sudden increase in noise level, and a transmitter tuned over the widest range possible may produce extra responses other than the image response. If the cold end of the rf choke feed is accessible, and found to be "hot", the appropriate measures can be taken.

It is usual to tone modulate the receiver local oscillator (as well as the transmitter) so that cw transmissions, for example

from crystal-controlled calibrating sources, can be detected, and this is normally done by modulating the applied voltage. In these cases it is desirable to determine the frequency/voltage relationships of the particular oscillator to determine its optimum working voltage, as well as to check that the frequency varies smoothly over the range required, which is equivalent to about $\pm 0.5V$. This, of course, should be done at both ends of the tuning range. As a rough guide the voltage should be adjusted for maximum output and then reduced until the output power falls by about 30 per cent.

References

- [1] *Radio Communication*, Vol 48, July 1972, p442.
- [2] "A Gunn device transmitter (10GHz)", Mullard.
- [3] *Radio Communication*, Vol 47, April 1971, p271.
- [4] *Radio Communication*, Vol 49, February 1973, p106.
- [5] *Radio Communication*, Vol 49, October 1973, p692.
- [6] *Radio Communication*, Vol 48, March 1972, p158.
- [7] *Radio Communication*, Vol 49, March 1973, p193.

Downward modulation and business mobile transmitters

by B. PRIESTLEY, G3JGO

MANY amateurs start their careers with a converted ex-business mobile transmitter on either 4 or 2m. Often the results are not as good as the equipment is capable of, but the new licensee is understandably a little hesitant about diagnosing the fault and rectifying it. The following notes are designed to help with one commonly-found problem.

On the vhf bands a large depth of modulation is particularly desirable since a signal can be quite weak and yet free of QRM. Under these circumstances the receiver noise level will limit readability by making the level of modulation seem less than it actually is, ie the detector is "captured" by noise. Thus it is essential to have the maximum amount of undistorted modulation on the carrier.

Unfortunately, if grid drive is lacking the transmitter power amplifier may have a very poor upward modulation capability, ie the modulating power applied to its anode and screen may not produce a proportional rise in rf output (see Fig 1). In fact, this situation seemed to be so prevalent on the 2m band that the author was reduced to tuning in the BBC to make sure that the receiver and scope did not suffer from some form of distortion!

The results of this "downward modulation", so called because the rf output decreases on modulating, are:

- (1) reduced communications effectiveness;
- (2) increased valve dissipation and reduced life;
- (3) splatter—possibly with enhanced tvi and certainly unpopularity among local amateurs.

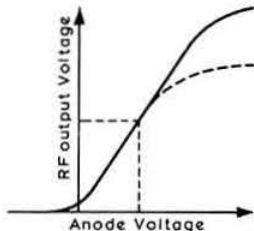


Fig 1.

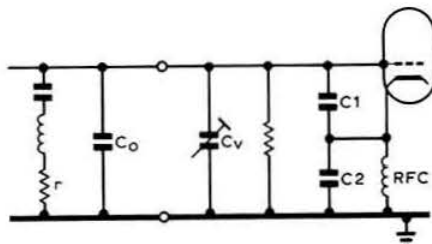


Fig 2.

Since a well-designed transmitter could be expected to have a distortion of, say, five per cent at 80 per cent modulation, an observed upward modulation capability of no more than 40 per cent with a considerable amount of distortion indicates something seriously wrong—probably shortage of drive. This may not show up without modulation but remember that a 10W pa is running at 40W input on modulation peaks and requires drive appropriate to a 40W cw stage. Assuming that the driver stages are correctly tuned up and the valves are not failing, the most likely cause is the use of unsuitable quartz crystals.

Most business mobile sets are designed for modern miniature crystals such as the HC6/U. Substitution of a 10XS or FT243 will result in less oscillator excitation and thus less pa grid drive. Compared with the HC6/U the older crystals show higher Co and r, both of which will reduce the excitation (see Fig 2). Removing Cv will help, but it may be necessary to reduce C1 and/or C2 as well. If even this does not suffice, due to the low gm of the valve in use, then there are two choices, either substitute another valve, or convert the stage to a buffer amplifier driven by a transistor oscillator perhaps on the lines of the circuit by G3SBA¹.

When the transmitter is modulating correctly the rf output will show a slight rise and the anode current will remain almost constant. It now remains to reset the modulation and clip level controls and see who is the first to tell you how much better the signal is!

¹ "Put a transistor in your cathode". *Radio Communication* May 1970, p 299.